Title	How Many Steps to Represent Individual Gait?
Authors(s)	Ader, Lilian Genaro Motti, McManus, Killian, Greene, Barry R., Caulfield, Brian
Publication date	2020-06-26
Publication information	Ader, Lilian Genaro Motti, Killian McManus, Barry R. Greene, and Brian Caulfield. “How Many Steps to Represent Individual Gait?” ACM, 2020.
Conference details	The 12th ACM SIGCHI Symposium on Engineering Interactive Computer Systems, Sophia-Antipolis, France, 23-26 June 2020
Publisher	ACM
Item record/more information	http://hdl.handle.net/10197/12219
Publisher's statement	© ACM, 2020. This is the author's version of the work. It is posted here by permission of ACM for your personal use. Not for redistribution. The definitive version was published in EICS '20 Companion: Companion Proceedings of the 12th ACM SIGCHI Symposium on Engineering Interactive Computing Systems, https://doi.org/10.1145/3393672.3398638.
Publisher's version (DOI)	10.1145/3393672.3398638

How Many Steps to Represent Individual Gait?

Lilian G. Motti Ader
SPHPSS, CeADAR
University College Dublin
Dublin, Ireland
lilian.mottiader@ucd.ie

Killian McManus
SPHPSS, Insight Centre
University College Dublin
Dublin, Ireland
killian.mcmanus@insight-centre.org

Barry R. Greene
Kinesis Health Technologies Ltd.
Dublin, Ireland
barry.greene@kinesis.ie

Brian Caulfield
SPHPSS, Insight Centre
University College Dublin
Dublin, Ireland
b.caulfield@ucd.ie

ABSTRACT

Assessing and reproducing user's mobility has multiple purposes for interactive systems. In particular, the quantification of gait parameters has been used for user modelling, virtual environments, and augmented reality. While many technologies can be used to assess gait, measuring spatio-temporal parameters and their fluctuations, it is important to evaluate how many steps are necessary to represent the gait pattern of an individual, in order to provide better feedback to the user and improve user experience. In this preliminary study, we evaluate the intra-session reliability of spatio-temporal gait parameters for 24 healthy adults walking two trials of 15m in a corridor. Angular velocity data were acquired from body-worn inertial measurement units attached to participants' right and left shanks. An adaptive algorithm was applied for gait event detection, and gait parameters were analyzed according to pre-defined numbers of steps extracted from the full length of the trial. The main contribution of the present analysis is to present a method of gait event detection, segmentation and analysis that can be used for adjusting interactive systems to individual users.

CCS CONCEPTS

• Human-centered computing • Human computer interaction (HCI) • HCI design and evaluation methods • User models

KEYWORDS

Gait analysis; reliability; motion-based interaction; walking

ACM Reference format:

Lilian G. Motti Ader, Killian McManus, Barry R. Greene and Brian Caulfield. 2020. How many steps to represent individual gait? In *ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS'20 Companion). June 23-26, 2020, Sophia-Antipolis, France. ACM, New York, NY, USA, 6 pages.* https://doi.org/10.1145/3393672.3398638

EICS '20 Companion, June 23–26, 2020, Sophia Antipolis, France

ACM ISBN 978-1-4503-7984-7/20/06...$15.00
https://doi.org/10.1145/3393672.3398638

1 Introduction

Motion-based interaction is a very exciting field of design because of advances in technologies to detect and record data from human movements. For example, mobile devices (e.g. smartphones) and wearables (e.g. smartwatches) have embedded accelerometers and gyroscopes to track device's orientation; headsets (e.g. headphones, virtual reality headsets) can adapt audio and feedback according to movements of the users' head; and sensors in the environment are used to track mobility and recognize patterns of activity.

Gait assessments have many applications for designing interactive systems. Technologies enabling gait analysis are used in areas as Health and Sports Sciences, but also in Human-Computer Interaction (HCI) in applications such as enabling for example digital human modelling for simulation [1], redirected walking for locomotion in virtual environments [2], assisted navigation and augmented reality systems [3].

Walking is the result of a fine coordination of neurological, motor and sensorial systems [4]. The use of technologies enables objective measurement of gait spatio-temporal parameters, from simple numerical values such as step counting, to more complex analysis as stride length variability. However, assessing and representing data from human movements is very challenging in terms of machine processing (e.g. data capture, treatment) and human factors (e.g. participant's abilities, morphologies, fatigue).

In addition, technologies and algorithms for gait assessment need to consider individual differences affecting pace and mobility. For example, average stride length usually depends on user's height. Users who are tall usually walk with larger stride length, travel a pre-defined distance with less steps, which can generate interaction problems (e.g. getting out of the interaction zone) as well as safety issues (e.g. hitting a wall).

Instead of relying on average values and fixed thresholds for gait event detection, algorithms can be designed to adjust event detection and provide adequate feedback to each user. For motion-based interaction, adaptive algorithms can support more realistic representation of walking and locomotion, with possible effects on segmentation of movements (e.g. bilateral gait) and comfort of use (e.g. reduction of motion sickness).

In order to improve gait assessment and representation for interactive systems, it is important to study the reliability of gait parameters, as different methods can be applied for data capture and treatment. One challenge to address is to define how much data, or how many steps, are necessary for reliable assessment of an individual's gait.

This paper presents a preliminary study on the effects of extracting pre-defined numbers of steps from the full length of a walking trial and the reliability of spatio-temporal gait parameters, calculated using a previously published adaptive algorithm [5]. Twenty-four healthy adults walked two trials of 15m in a corridor, while acceleration data was acquired from body-worn inertial measurement units attached to participants right and left shanks. The results of the intra-session reliability analysis show how the number of gait cycles included in the analysis affect the calculated measures to represent gait patterns for an individual.

2 Methods

2.1 Procedures

Participants were a sample of convenience recruited from the community and local area. A total of 24 healthy adults, mean age 30.8±8 years, height 172.8±8.7 cm, weight 72.2±11.5 kg, 7 females (29%). Participants did not suffer from any neurological or musculoskeletal disorders. All participants provided informed consent.

Two inertial sensors were attached to each participant's shanks (about 10 cm below their knees) using dedicated Velcro straps. Each sensor contained a tri-axial accelerometer and a tri-axial gyroscope (sampling rate 102.4 Hz). Data were acquired in real time using dedicated software (Kinesis Gait™, Kinesis Health Technologies Ltd., Dublin, Ireland) and recorded via Bluetooth on a tablet device for offline analysis.

Participants were instructed to walk at a comfortable self-selected walking speed and start with their dominant foot (right or left). Each participant did two walking trials of 15m along a corridor.

2.2 Gait Events Detection

The medio-lateral angular velocity is recorded from right and left sensor's gyroscopes, as specified in the literature [6]. After calibration, raw gyroscope signal represents the shank angular velocity. Calibration, data treatment and artefact rejection of sensor data is reported elsewhere [5]. Detection of gait events and calculation of spatial and temporal parameters follow the procedures described in published algorithms [5,7,8].

Figure 1 represents gait event detection and segmentation on a sample of shank angular velocity.

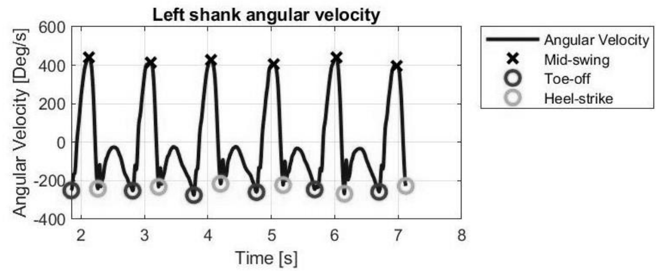

Figure 1: Plot representing gait event detection from left medio-lateral shank angular velocity and six strides of steady state gait extracted from the full length of the walking task for one participant (female, 34 years old, height 165 cm)

The analysis of the medio-lateral shank angular velocity signal allows the identification of heel strike (initial contact) and toe-off (terminal contact) times representing the mobilization of each leg. From these events, we can estimate the sequence of events for a bipedal gait cycle and calculate gait spatio-temporal parameters:

- Stance time: heel strike to toes-off of the same foot (mean times, averaged across both legs, in seconds)
- Swing time: the foot is not in contact with the ground between toes-off and heel strike (mean times, averaged across both legs, in seconds)
- Stride time: time between successive heel strikes of the same foot, corresponds to a gait cycle (mean times, averaged across both legs, in seconds)
- Step time: heel strike of one foot to heel strike of opposite foot (average of times, in seconds)
- Double support: proportion of gait cycles spent on both feet (averaged across multiple gait cycles, expressed as percentage)
- Stride length: distance travelled during swing time estimated from orientation angle of the shank relative to the vertical, considering the participant's height (average value in meters)
- Stride velocity: stride length divided by stride time (cm/s), averaged across both legs.

To estimate the variability, the Coefficient of Variation (CV) of the spatio-temporal gait parameters was used calculated as the standard deviation (SD) divided by mean values within subject across multiple gait cycles, expressed as a percentage.

Figure 2 illustrates the gait cycles phases.

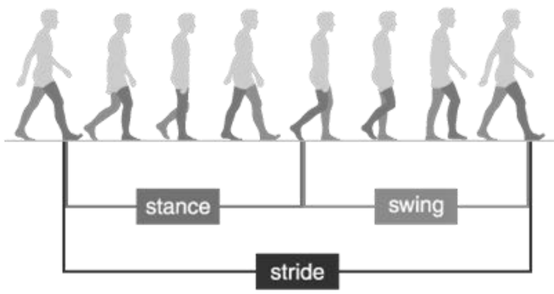

Figure 2: Chart illustrating gait cycles phases (Reproduced with permission from Kinesis Health Technologies © Source: https://www.kinesis.ie/gait/)

2.3 Data Segmentation

Gait assessments should consider the different phases of a walking trial: gait acceleration or initiation phase, steady state gait and deceleration or termination phase. For the purposes of the present study, the analysis focuses on steady state gait data. To remove gait initiation phase, the segmentation of gait data ignored the first gait cycle (i.e. first step each leg) and included data from the 3rd step, as commonly reported in the literature [9,10].

Parameters relying on data from both legs can only be estimated from a minimum of two gait cycles. Variability of temporal parameters and spatial parameters requires at least three gait cycles. Participants executed different number of steps to complete the trials. In order to include all the participants, a maximum of seven gait cycles was extracted from the total length of the trial (14 strides, or seven strides per leg). Seven gait cycles represent the total steady state gait for the walking trial in the present study.

2.4 Data Analysis

The intra-session reliability was calculated using intraclass correlation coefficients (ICC(2,k)) [11,12] for each one of the gait parameters, for a pre-defined number of gait cycles, ranging from 2 to 6. The results were classified according to the ICC scores indicating reliability is excellent (ICC>=0.90), high (0.75>=ICC<0.90), moderate (0.50>=ICC<0.75) or poor (ICC<0.50) [11]. Data analysis was conducted offline using MATLAB (version R2019a, MathWorks, VA, USA).

3 Results

3.1 Intra-session reliability

Spatio-temporal gait parameters calculated from mean values present excellent reliability from two gait cycles (four strides, two of each leg). Figure 3 presents reliability of spatio-temporal gait parameters according to the number of gait cycles.

Reliability of parameters related to the variability tend to increase with the number of gait cycles included in the analysis. Most parameters describing gait variability reach moderate reliability from five gait cycles and good reliability when six gait cycles or more are included in the analysis. Figure 4 presents reliability of variability of temporal gait parameters according to the number of gait cycles.

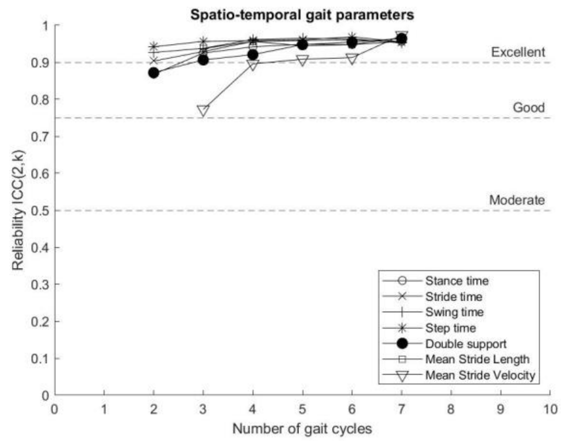

Figure 3: Reliability of spatio-temporal gait parameters according to the number of gait cycles included in the analysis

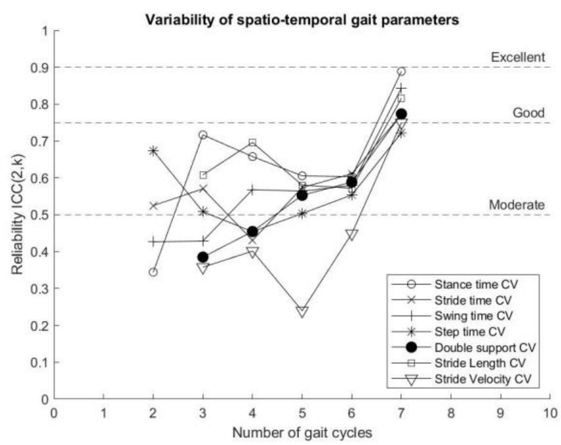

Figure 4: Reliability of the variability of spatio-temporal gait parameters according to the number of gait cycles included in the analysis

4 Discussion and Conclusion

The present study analyzed the intra-session reliability of spatio-temporal gait parameters and their variability, according to a pre-defined number of gait cycles representing steady-state gait and extracted from the full walking trial. In the present study, data collected with body-worn inertial sensors from participants' right and left shanks were calculated after an adaptive algorithm for gait event detection.

Results show that the selected algorithm for adjusting gait event detection to each individual can obtain reliable measures for parameters based on averaged values from 3 gait cycles (6 steps, 3 from each leg). The reliability of parameters representing gait variability increases with the number of steps included in the analysis and values might need to be readjusted for a better representation of gait in long walking tasks.

This preliminary study showed that the combination of the selected adaptive algorithm, extracting gait events from data collected from the right and left shanks, and a windowed approach, extracting a pre-defined number of gait cycles from the full length of the walking task, should be explored with a larger number of participants to further evaluation of the reliability of measures of individual gait assessments.

The gait signature, or the individual characteristics of walking, is the result of the fine tuning of neuro, motor and sensorial systems, ensuring postural stability and balance control. We expect that adaptive algorithms can enable more realistic representation of walking and locomotion, improving the correspondence of real and virtual displacements.

ACKNOWLEDGMENTS

L.G.M.A. receive funding from the EU H2020 under the Marie Skłodowska-Curie Career-FIT fellowship (Co-fund grant No. 713654). K.McM. is an employee at Kinesis Health Technologies Ltd, as part of the Irish Research Council Employment-Based Post-Graduate Programme. B.R.G. is a director of Kinesis Health Technologies Ltd, a company with a license to commercialize Kinesis Gait™.

REFERENCES

[1] N. Kaklanis, P. Biswas, Y. Mohamad, M.F. Gonzalez, M. Peissner, P. Langdon, D. Tzovaras, C. Jung, Towards standardisation of user models for simulation and adaptation purposes, Univers. Access Inf. Soc. 15 (2016) 21–48. https://doi.org/10.1007/s10209-014-0371-2.

[2] J. Walker, Redirected Walking in Virtual Environments, Cs.Mtu.Edu. (2013) 1–14. http://cs.mtu.edu/~jwwalker/files/cs5760-jwwalker-topicpaper.pdf.

[3] M. Sra, A. Mottelson, P. Maes, Your place and mine: Designing a shared VR experience for remotely located users, DIS 2018 - Proc. 2018 Des. Interact. Syst. Conf. (2018) 85–98. https://doi.org/10.1145/3196709.3196788.

[4] J.M. Hausdorff, Gait variability: methods, modeling and meaning Example of Increased Stride Time Variability in Elderly Fallers Quantification of Stride-to-Stride Fluctuations, 9 (2005) 1–9. https://doi.org/10.1186/1743-Received.

[5] B.R. Greene, D. McGrath, R. O'Neill, K.J. O'Donovan, A. Burns, B. Caulfield, An adaptive gyroscope-based algorithm for temporal gait analysis, Med. Biol. Eng. Comput. 48 (2010) 1251–1260. https://doi.org/10.1007/s11517-010-0692-0.

[6] E.P. Doheny, T.G. Foran, B.R. Greene, A single gyroscope method for spatial gait analysis, 2010 Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBC'10. (2010) 1300–1303. https://doi.org/10.1109/IEMBS.2010.5626397.

[7] B.R. Greene, T.G. Foran, D. McGrath, E.P. Doheny, A. Burns, B. Caulfield, A comparison of algorithms for body-worn sensor-based spatio-temporal gait parameters to the gaitrite electronic walkway, J. Appl. Biomech. 28 (2012) 349–355. https://doi.org/10.1123/jab.28.3.349.

[8] U. Lindemann, B. Najafi, W. Zijlstra, K. Hauer, R. Muche, C. Becker, K. Aminian, Distance to achieve steady state walking speed in frail elderly persons, 27 (2008) 91–96. https://doi.org/10.1016/j.gaitpost.2007.02.005.

[9] K.S. Van Schooten, S.M. Rispens, P.J.M. Elders, J.H. Van Diee, Toward ambulatory balance assessment: Estimating variability and stability from short bouts of gait, 39 (2014) 695–699. https://doi.org/10.1016/j.gaitpost.2013.09.020.

[10] T.K. Koo, M.Y. Li, A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research, J. Chiropr. Med. 15 (2016) 155–163. https://doi.org/10.1016/j.jcm.2016.02.012.

[11] K.O. McGraw, S.P. Wong, "Forming inferences about some intraclass correlations coefficients": Correction., Psychol. Methods. 1 (1996) 390–390. https://doi.org/10.1037//1082-989x.1.4.390.